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Metal Impurity Transport Control in JET H-modePlasmas with Central *ICRH*

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12 See Appendix of F Romanelli et al., Proc. 22nd IAEA Fusion Energy Conf. 2008,Geneva, Switzerland

Motivation

- We need to fully understand the behaviour of impurities in reactor relevant plasmas as in ITER and Demo plasma dilution in the core will be a figure of merit (including fusion ashes).

- Also, as for many other parameters, impurities will need an active control system to guarantee stationarity of plasma conditions

Method

• Source mechanisms and transport across SOL and pedestal important but beyond the scope of this work, focused on core aspects.

• For impurities in the core what really matters is the relationship between D_impurities , D fuel and χe,i , since the relevant parameter is dilution.

Here we concentrate on D_impurities

To measure impurity transport one powerful means is to create impurity density perturbations as with laser ablation. Modelling of the transient evolutions of the appropriate signals provides an estimate of the transport coefficients.

Model based on 1D continuity equation with $\Gamma = -D\nabla n + vn$

+ accurate atomic physics to describe all of the ionization stages.

Peaking factor

$$-\frac{\nabla n_z}{n_z} = -\frac{v}{D}$$

>0 peaked profiles

<0 hollow profiles

Theory : several mechanisms can affect impurities in the plasma

- **Turbulence and impurity radial transport**

- *Curvature pinch (Perp Dynamics)* : inward ~~f(Z)~~
- *Parallel Compressibility* : Outward for TEM
  Inward for ITG ~ Z/A

- *Thermodiffusion* : Inward for TEM
  Outward for ITG ~ 1/Z → lower for high Z impurities

  - Curvature pinch changes sign with magnetic shear (Futatani)
  - Rotation and shear rotation inward for TEM and Outward for ITG (Camenen)
  - Centrifugal and Coriolis forces : outward advection (Clements/ Romanelli)
  - Electromagnetic effects ~ 10% of electrostatic ones (Hein)
  - RF induced ponderomotive forces - affect similarly D and v (Nordman)
  - High Impurity concentration: significant in case of TEM (Fulop/ Moradi)

- **Neoclassical radial transport**

  - *vneo / Dneo = Zi• (1/n• dn/dr - H• 1/T• dT/dr)* ; H approx 1

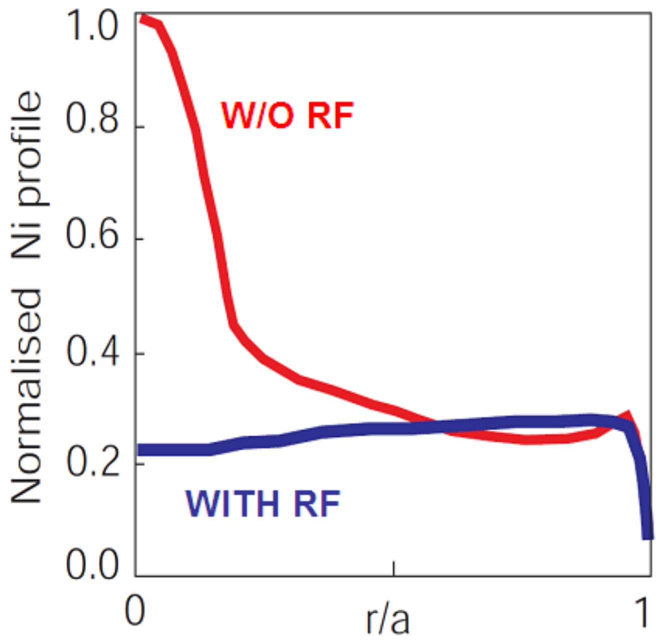
Experiment: central RF power and impurity pump out

RF (electron heating) pump out effect observed in several other experiments:
C-mod, DIII-D, JT-60, TCV
and also in non axisymmetric devices (W7-AS)

...but only few example of successful explaniation of radial flow reversal from the theory - AUG : TEM (Angioni et al. PPCF 2007)

JET: RF power is a means to control heavy impurities

JET discharges 58143 and 58142



M.E. Puiatti et al
PoP 13 2006

Steady state Ni profiles, calculated from exp v and D

Similar results obtained also in high density JET discharges

M.E. Puiatti et al .Plas. Phys.Contr. Fus. 44(2002)1863

This work: ICRH Power scan in JET

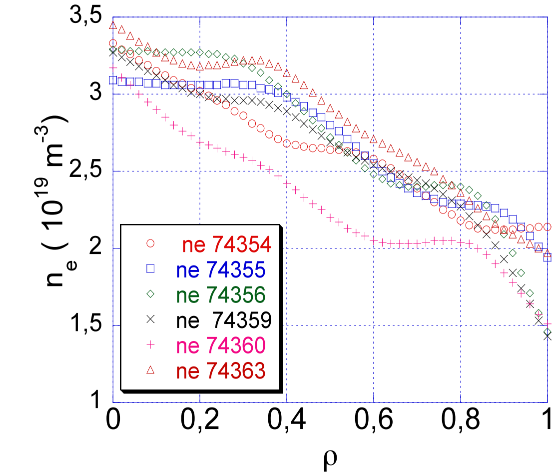
A series of dedicated H mode discharges with a RF power scan + LBO of Ni and Mo have been performed on JET to systematically analyze the effect of Central RF heating

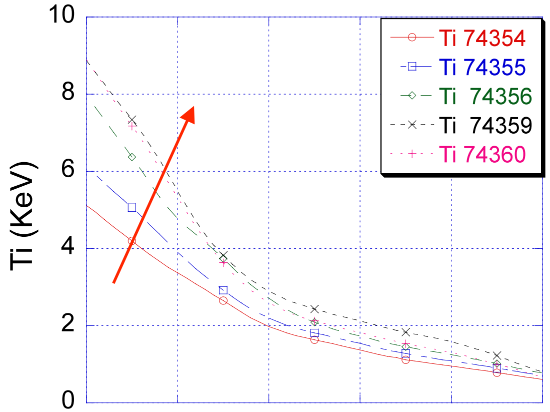
Main feature:

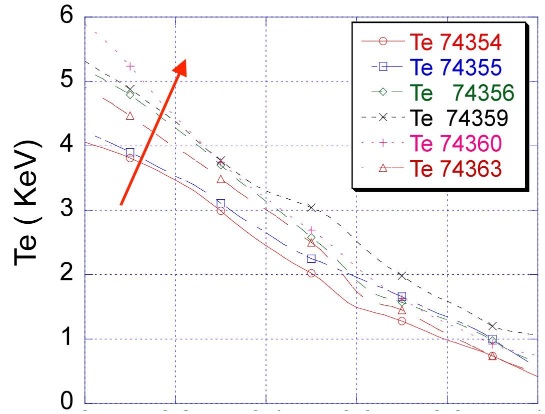
• ICRH heating: H minority, 5% concentration to heat electrons
• low collisionality (νeff< 0.2)
• about 12 MW NBI
• high central q to avoid sawteeth
• no total power (NBI + RF) conservation → effect of the RF scan on q, Te, Ti , ω profiles
• no significant MHD activity

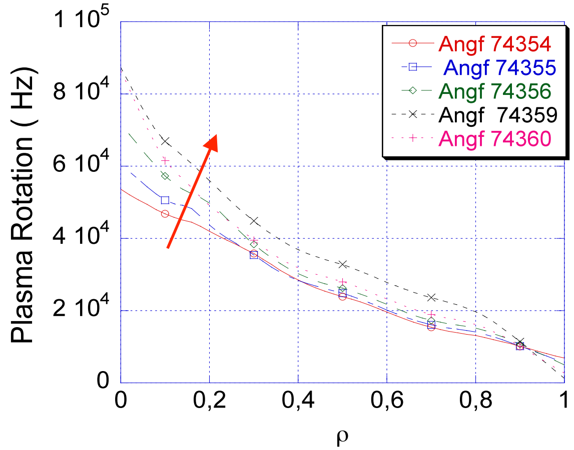
Main plasma profiles

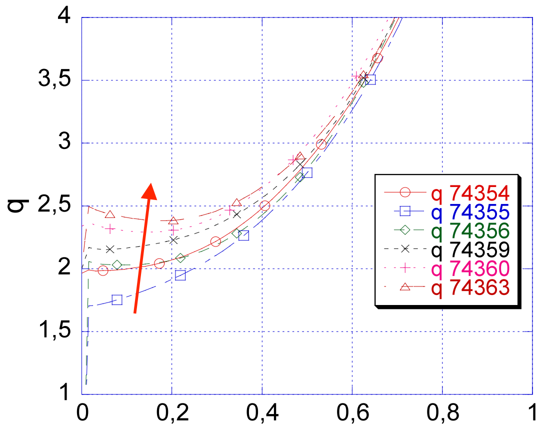
The RF power modifies the target plasma affecting mostly Ti , Te , bulk toroidal rotation and q



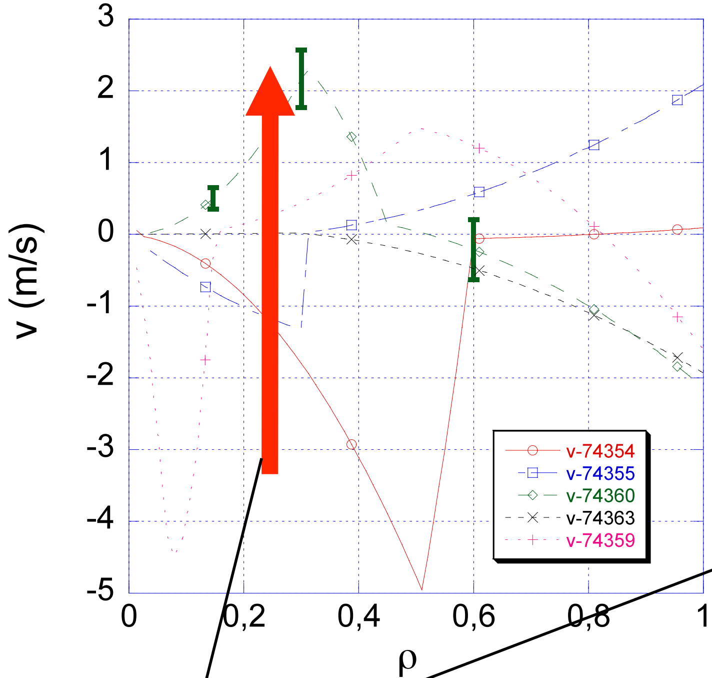




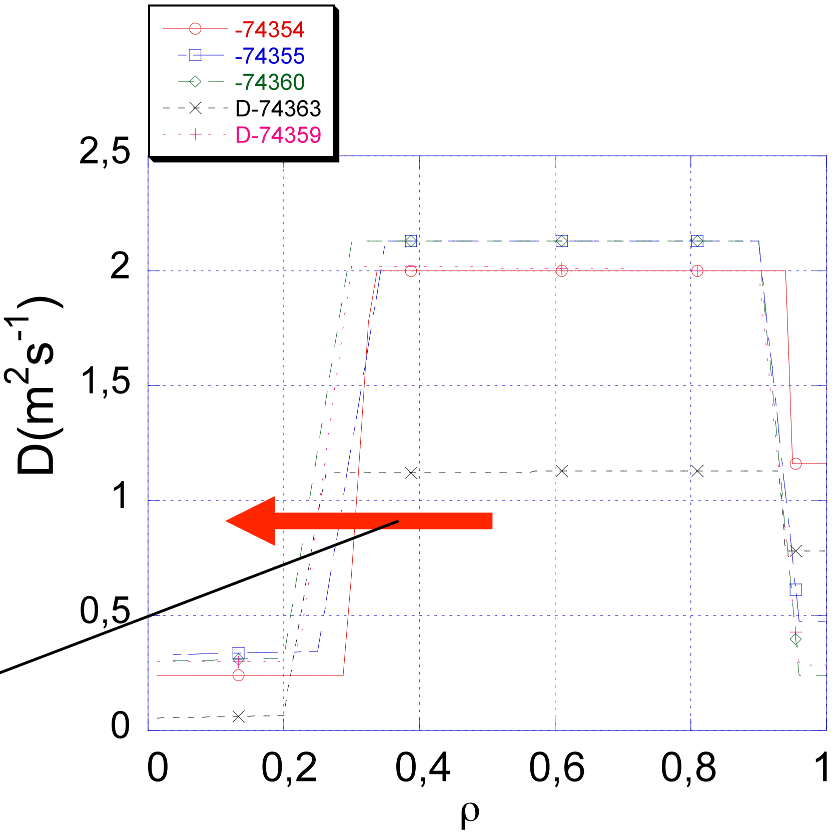




	(MW)
74354	0
74355	1
74356	2
74359	3
74360	3
74363	3



v (m/s)
ρ
v-74354
v-74355
v-74360
v-74363
v-74359

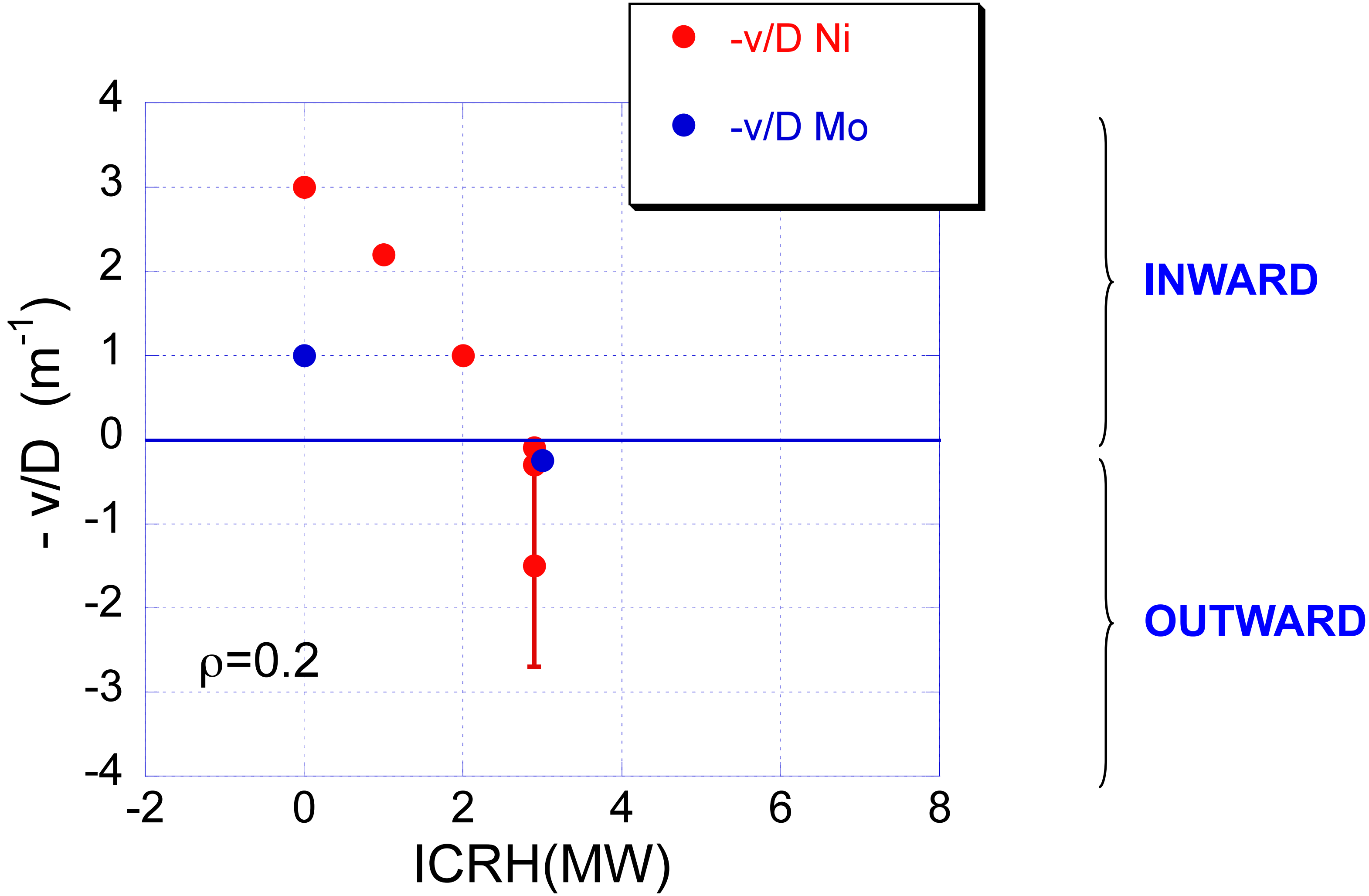


D(m^{2}s^{-1})
ρ
-74354
-74355
-74360
D-74363
D-74359

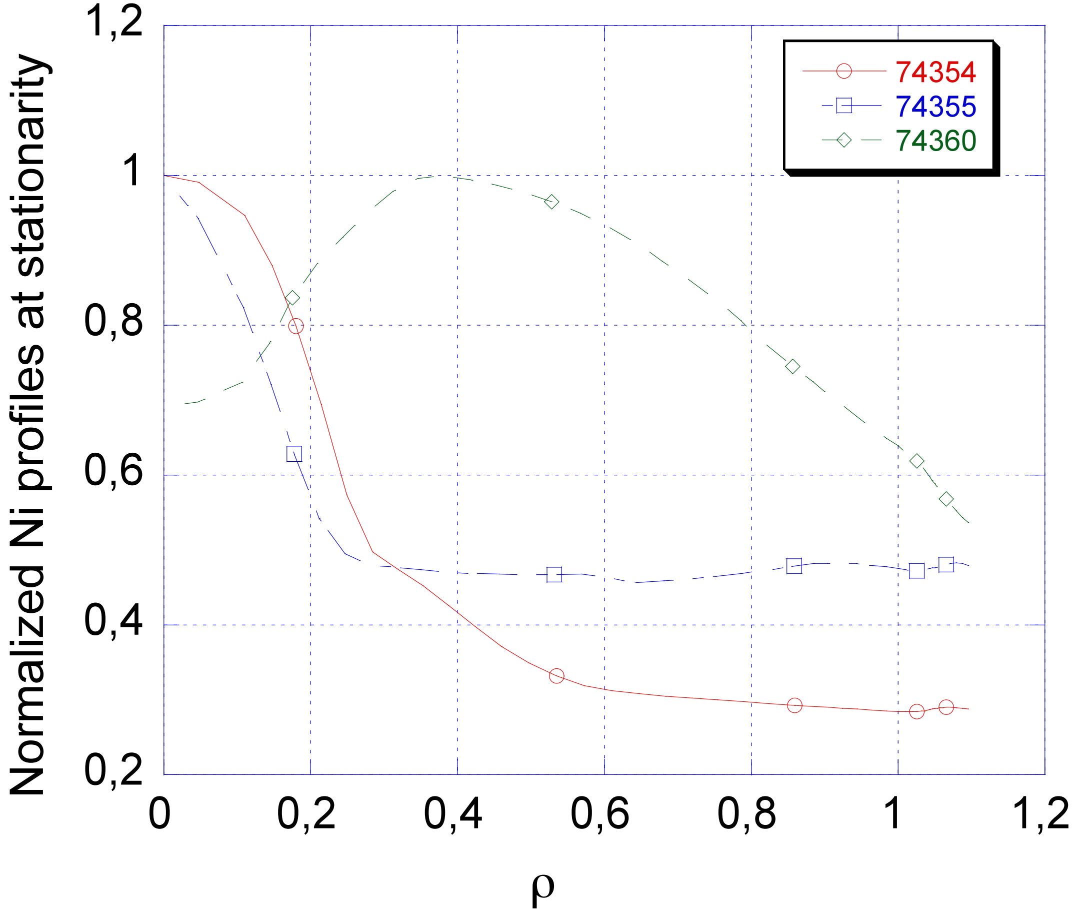
ICRH power

Mo(42) and Ni (28) have similar behaviour

Average between ρ = 0.2 and ρ = 0.3



Ni profiles extrapolated to stationary conditions

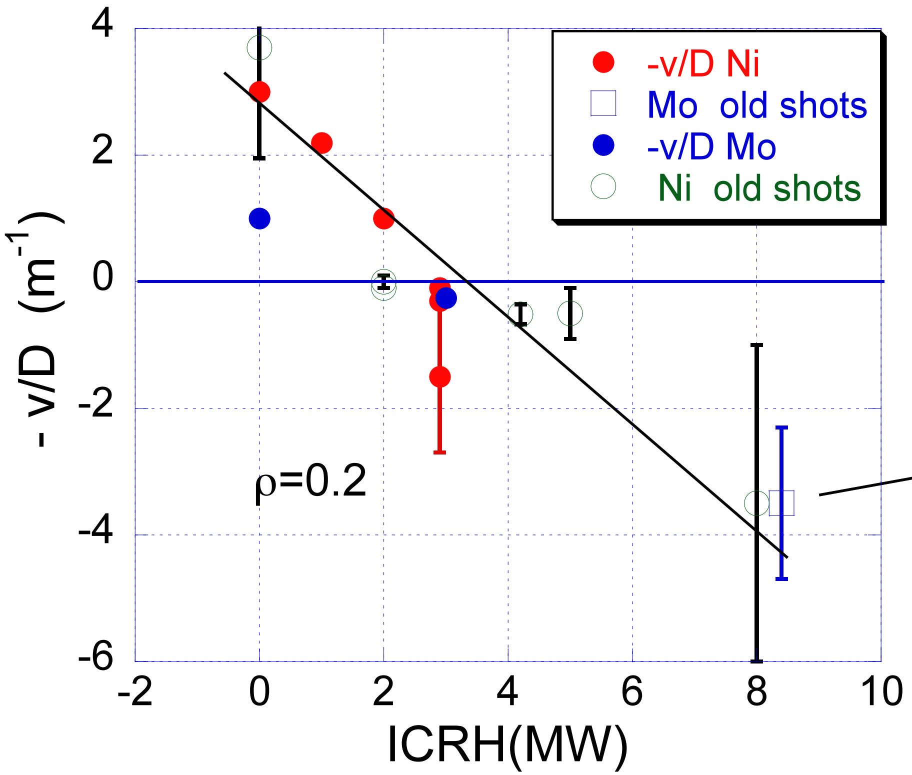


3 MW ICRH

1 MW ICRH

NO ICRH

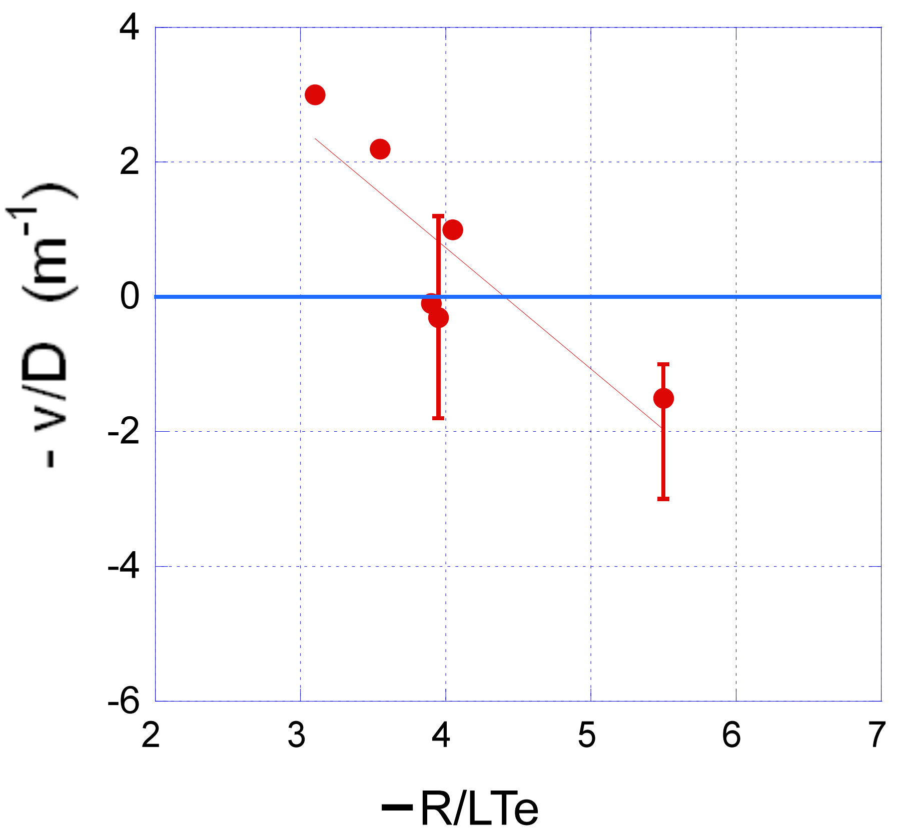
New data fit wider JET database



68383 – marginal H mode
Low collisonality,
Similar triangularity
and elongation

Good correlation of v/D(Ni) with R/LTe

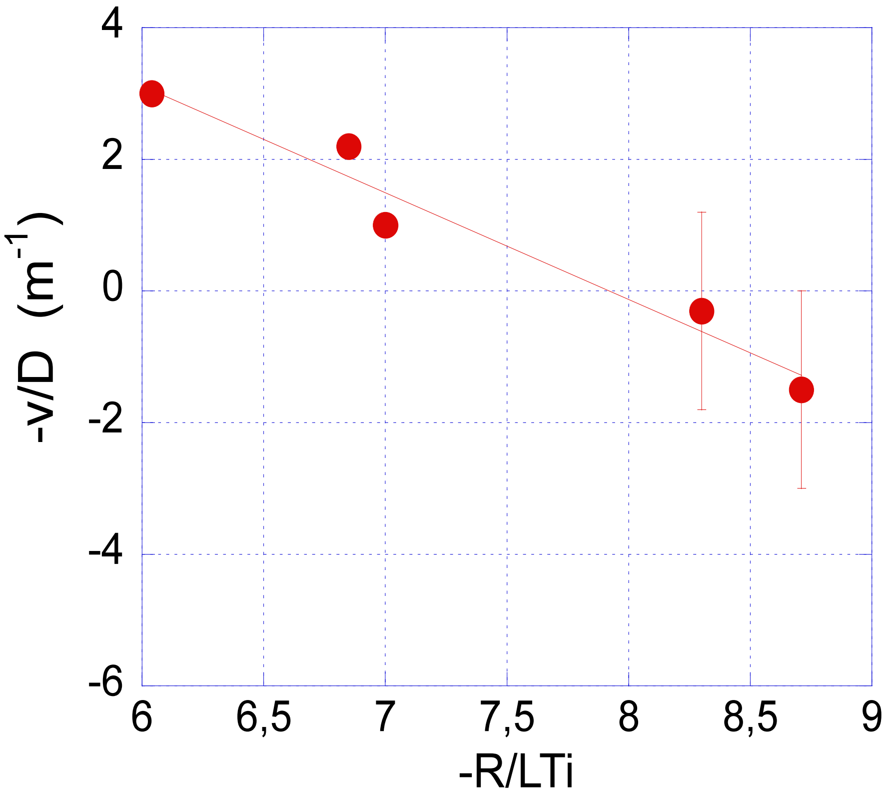
Average between ρ = 0.2 and ρ = 0.3



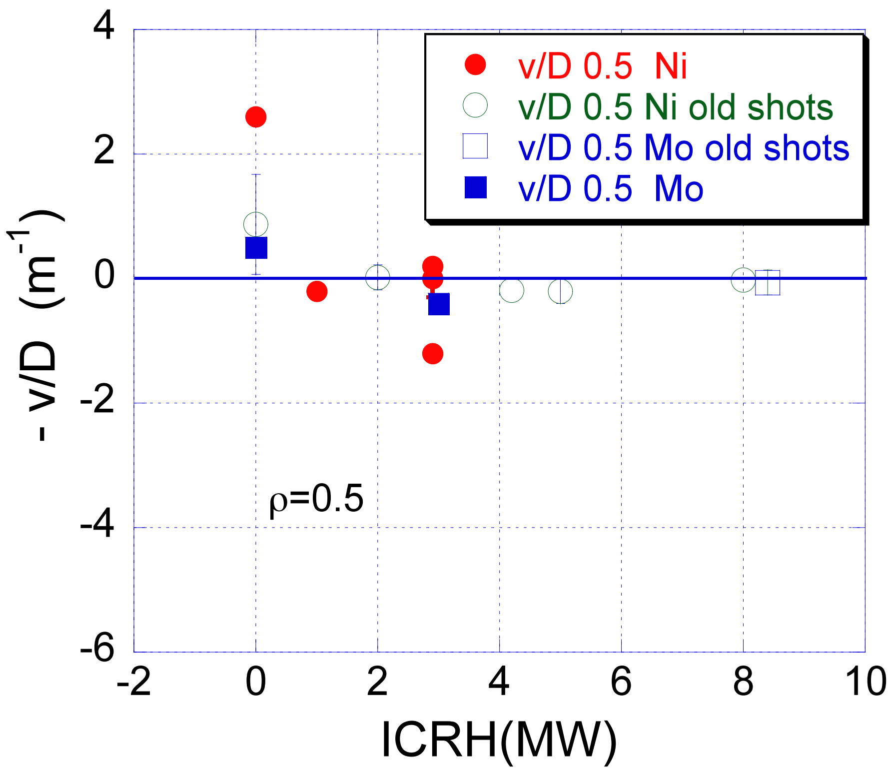
Still better correlation of v/D(Ni) with R/LTi

Average between ρ = 0.2 and ρ = 0.3

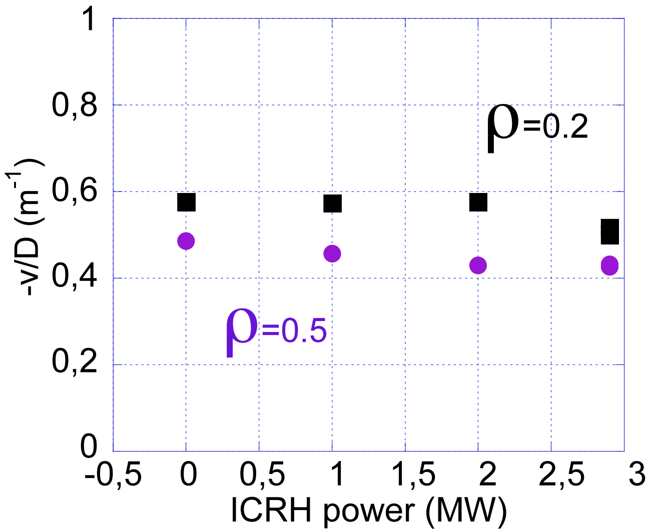
Neoclassical effect?



No dependence on ICRH power at ρ=0.5



Turbulence induced flow: no agreement with experiment



GS2 (linear, electrostatic) analysis shows trends in the right direction, but never provides an inversion of v/D (which may occur for ITG → TEM dominant mode transition,obtainable for instance with much lower Ti gradients than in JET experiments - see e.g. Angioni et al. PPCF 49, 2007);

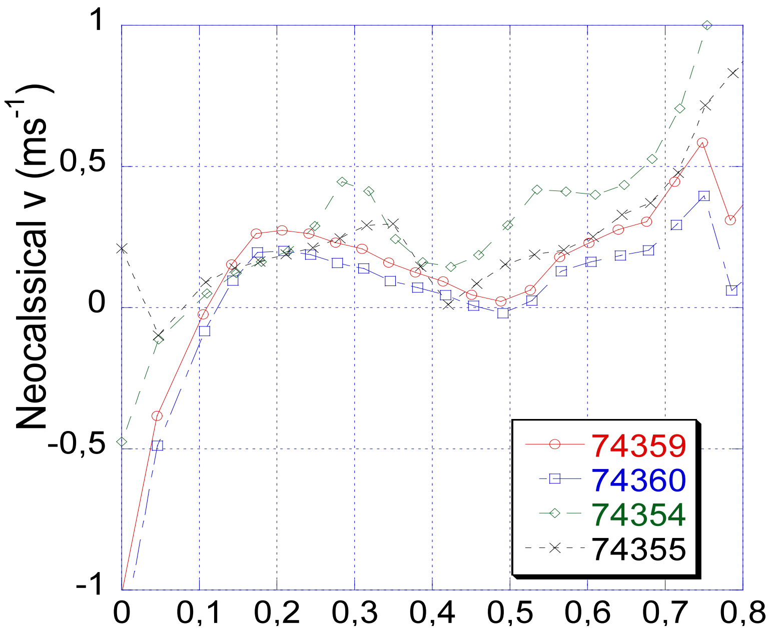
Tested also the addition of a hot H species (to simulate energetic ion tails after ICRH injection).

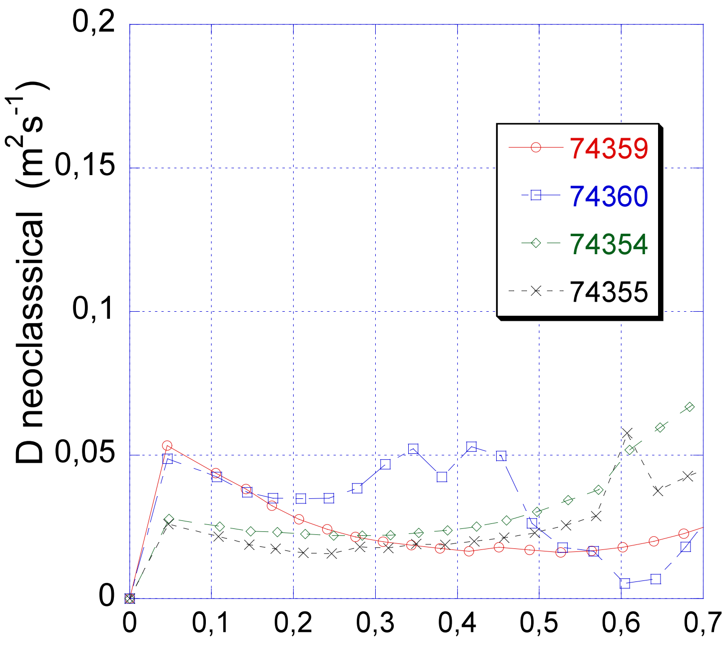
The impressive good correlation between v/D and R/LTi suggest a strong neoclassical contribution

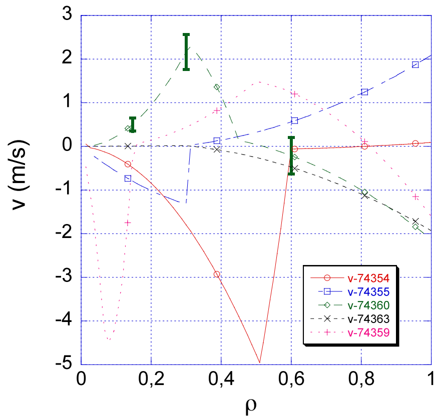
$$v_{neo} / D_{neo} = Z_i \cdot (1/n \cdot dn/dr - H \cdot 1/T \cdot dT/dr) \; ; \quad \text{H approx 1}$$

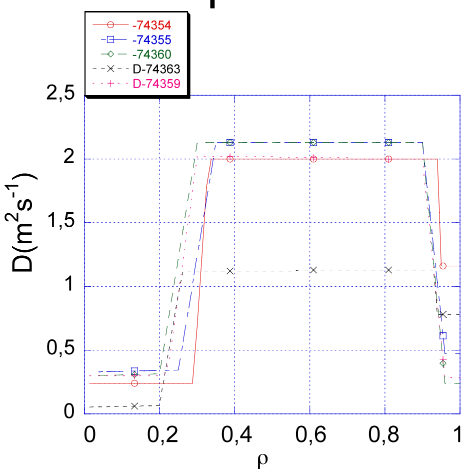
Flat density profiles and peaked ion temperature profiles screen impurities out

However: neoclassical V and D - from NCLASS – are small



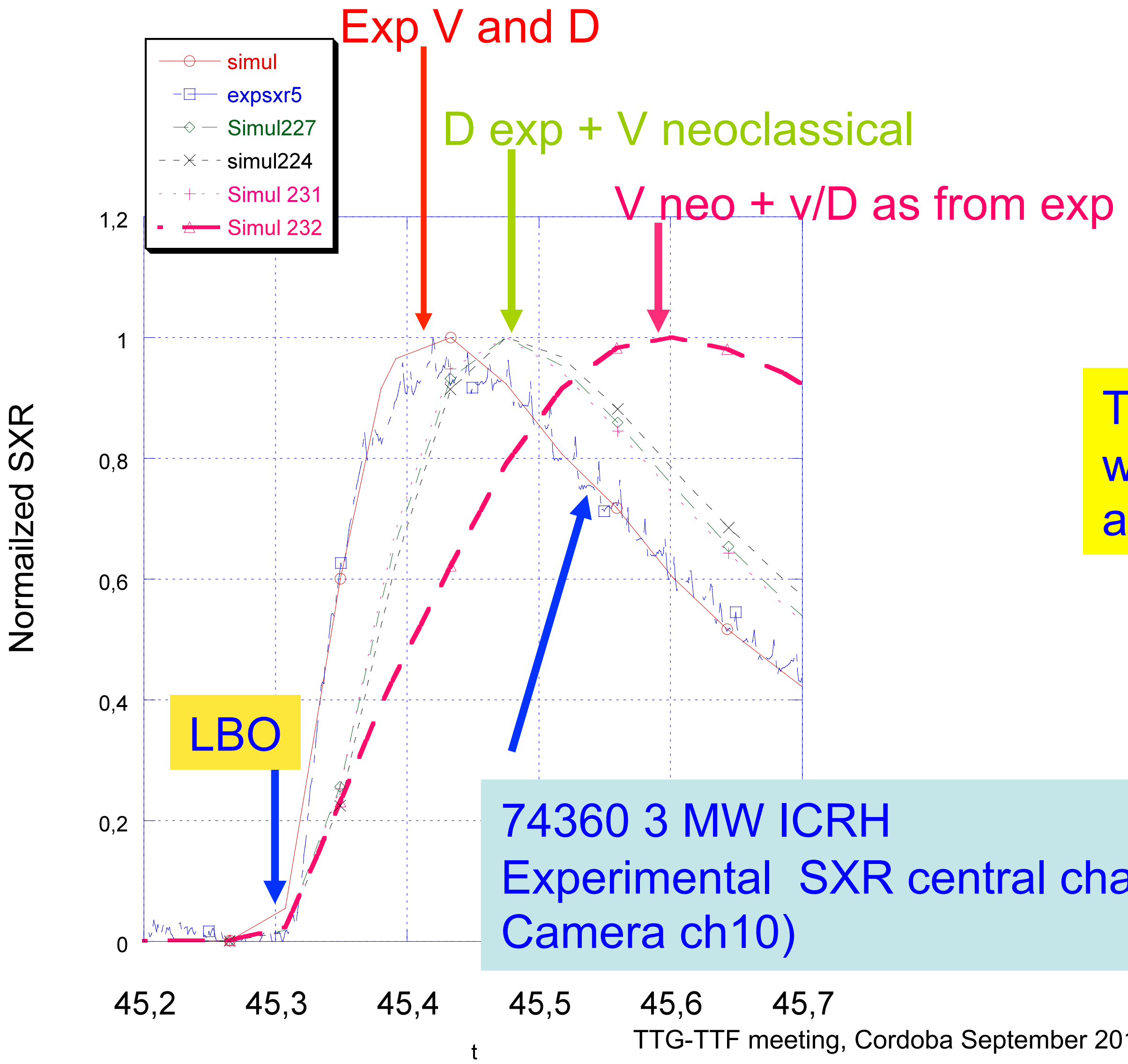






Sensitivity study on neoclassical v

Simulation of SXR emission with various combinations of transport parameters



Time differences well beyond the analysis uncertaintes

74360 3 MW ICRH
Experimental SXR central channel (J5 Camera ch10)

Summary and conclusions

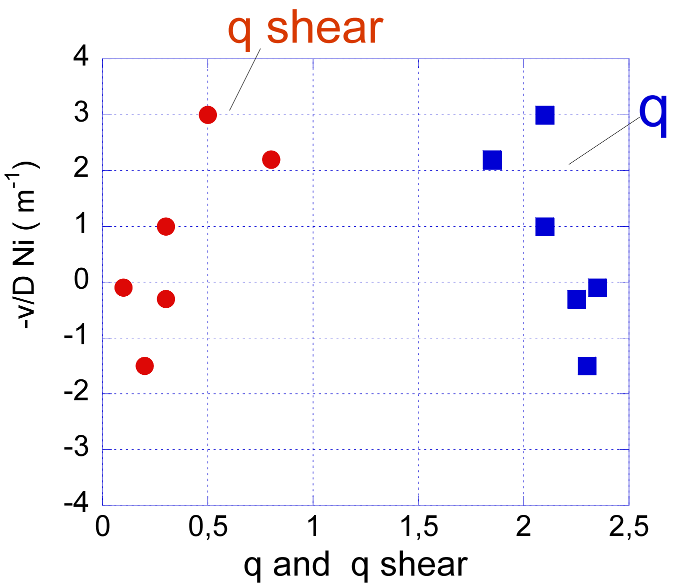
• Ni and Mo feature peaked profiles in JET H mode plasmas at low collisionality without sawthooth activity

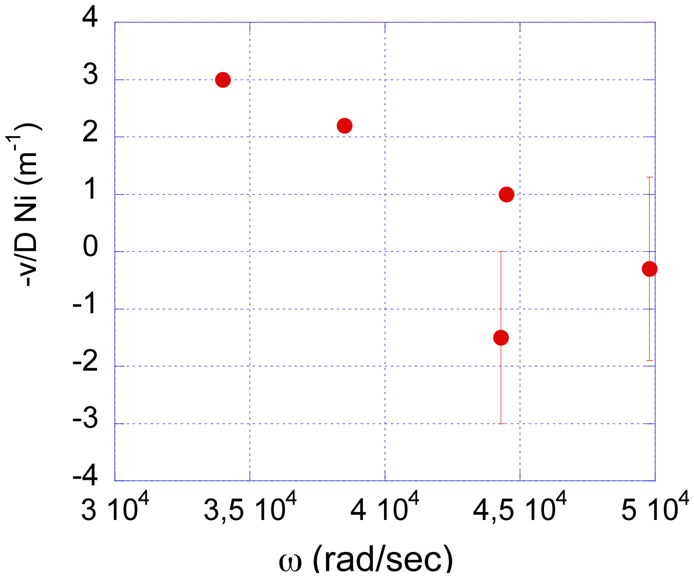
• Ni and Mo profiles may be made flat-hollow by applying 2-3 MW ICRH

• Impurity pump out has not been explained by turbulence calculations by GS2
(too large R/LTi to get outward turbulent flux)

• Very good correlation between v/D (Ni) and R/LTi , however absolute neoclassical values do not fit the experiment

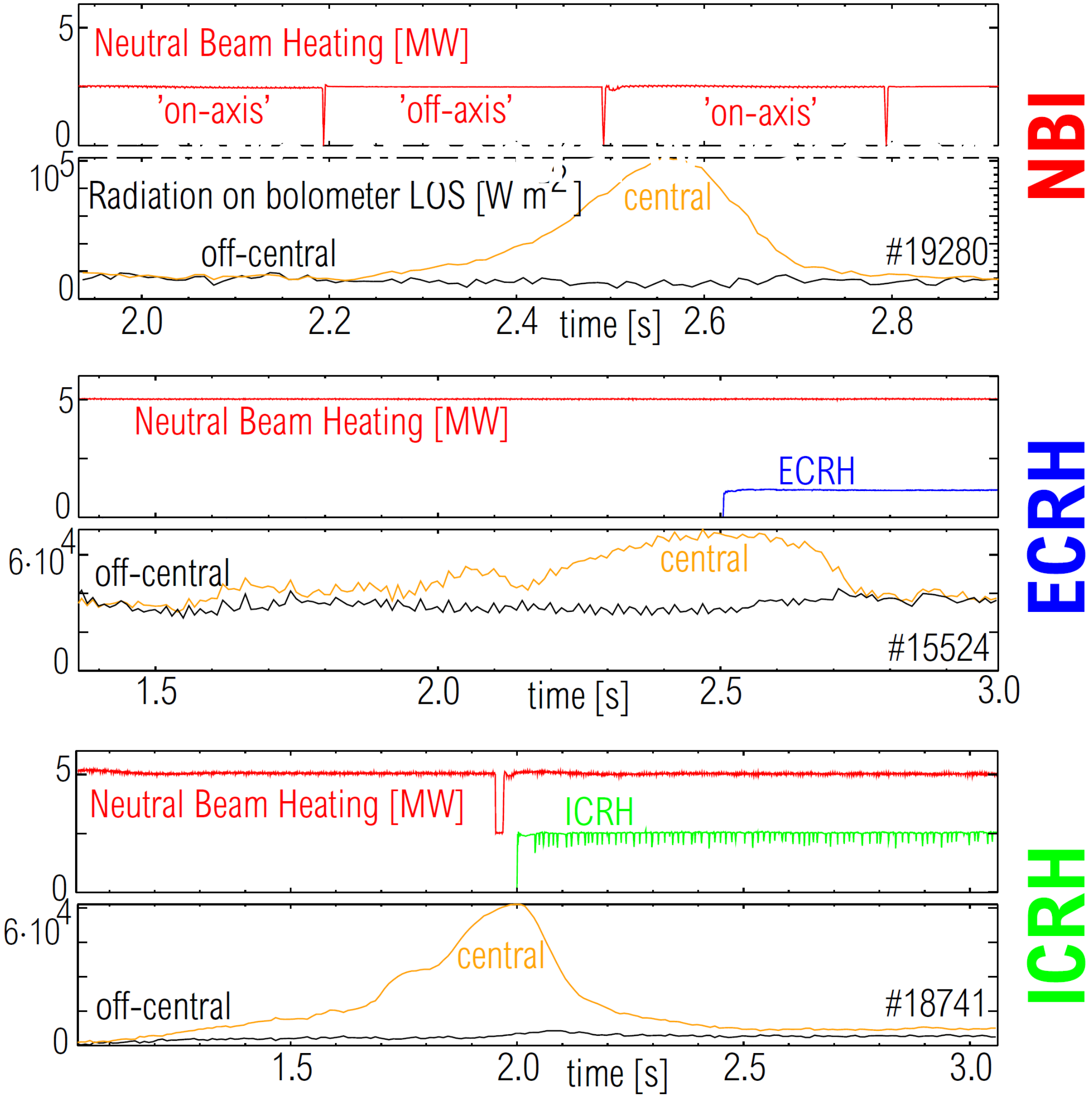
ρ **= 0.2 -0.3**





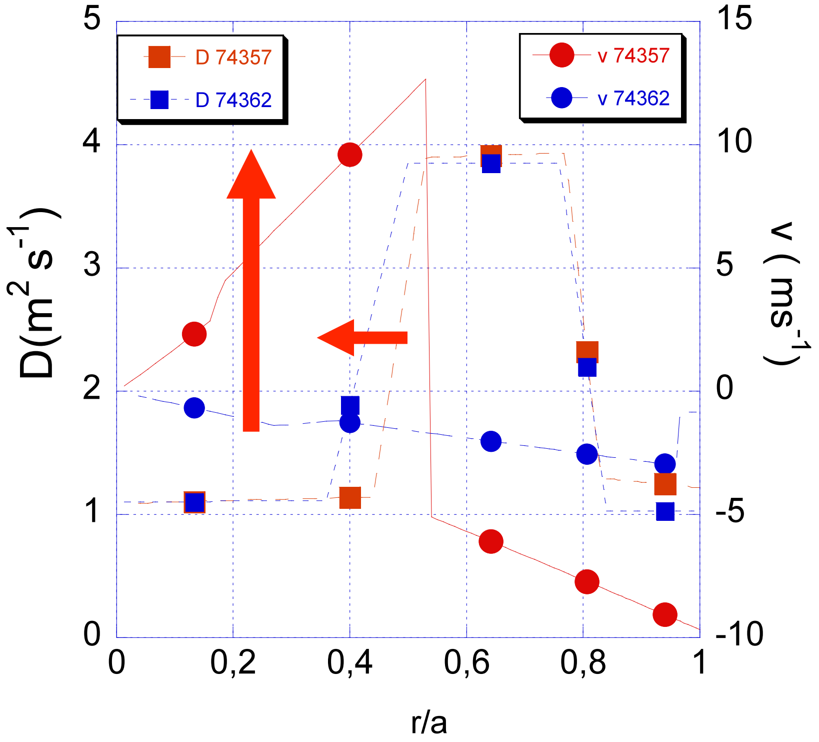
Toroidal rotation

Central power and impurity pump out



AUG
(Courtesy of T. Pütterich, EFPW 2009, Hungary)

RF (electron heating) pump out effect observed in several other experiments:
C-mod, DIII-D, JT-60, TCV
and also in non axisymmetric devices (W7-AS)

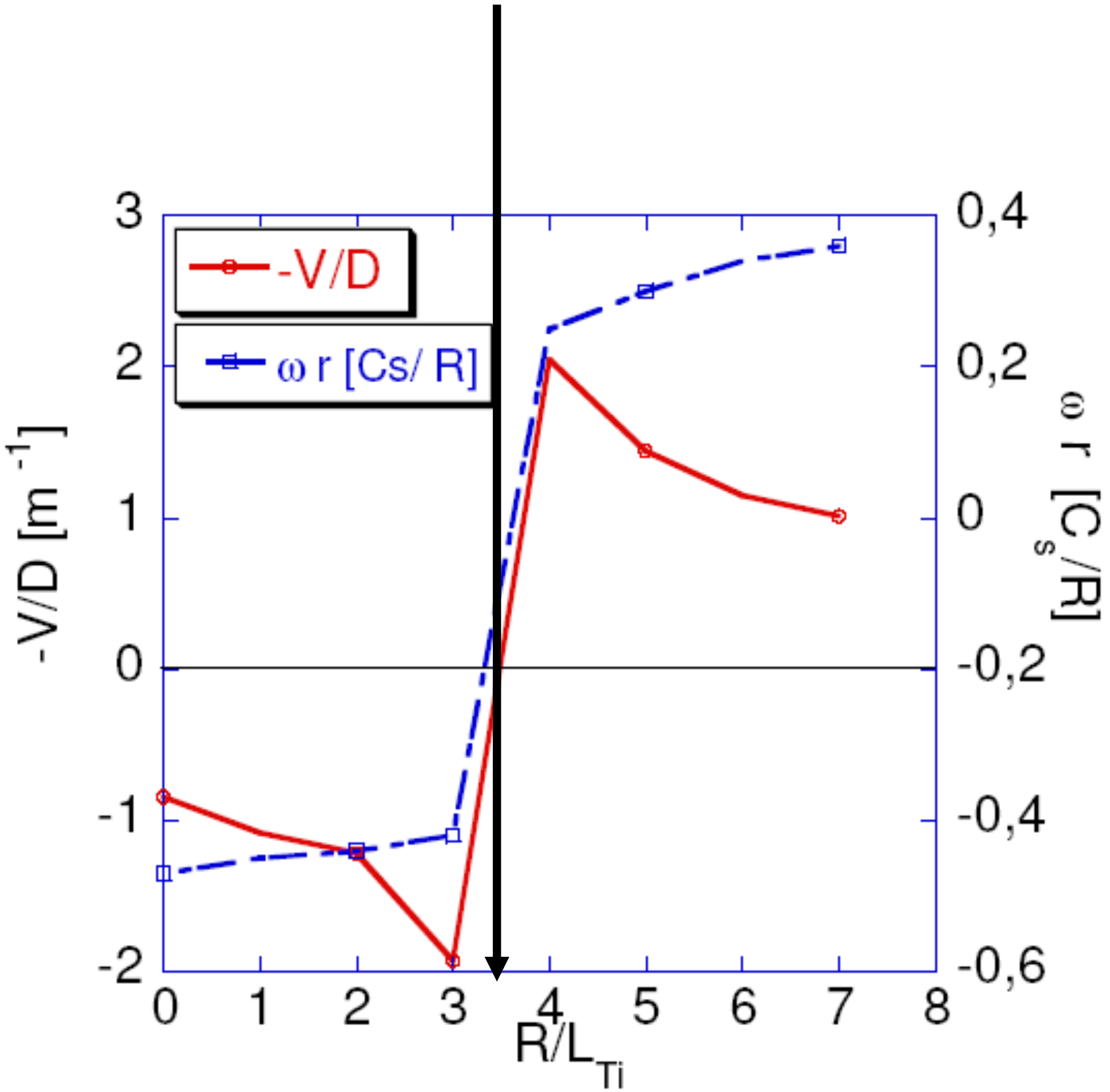


74357 NO ICRH

74362 3 MW ICRH

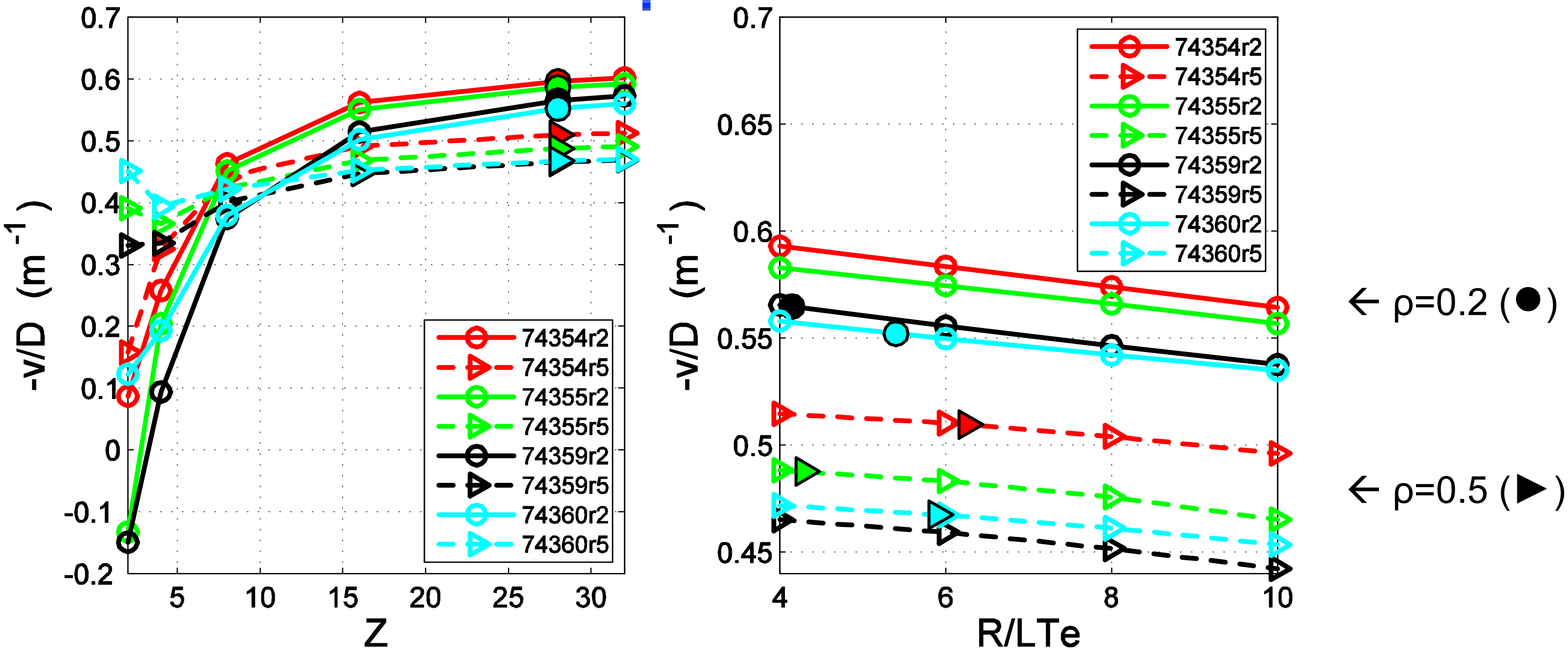
ICRH power

For the experimental ne and Te profiles of #68383 at r=0.35 , R/LTi < 3 would be necessary for the flow inversion.



L Carraro, C Angoni et al
EPS 2007 Warsaw

Gyrokinetic analysis (GS2)



• GS2 (linear, electrostatic) scan analysis shows trends in the right direction, but never provides an inversion of v/D (which it can be for ITG → TEM dominant mode transition reachable, for instance, for much lower Ti gradients - see e.g. Angioni et al. PPCF 49, 2007);

• Tested the addition of a hot H species (to simulate energetic ion tails after ICRH injection). The nature of turbulence remains ITG-dominated: the dominant mode frequency only slightly decreases for increasing beam energies, it never changes sign.

RF control of heavy impurities profile also in JET Elmy H-mode / HIGH DENSITY and Ar puffing

Shots 53548 , 53015 **WITH ICRH**:

convection may become outward

- Core diffusion decreases
- Core convection also decreases and may become outward

NO ICRH

Shot 52136: Strong inward convection

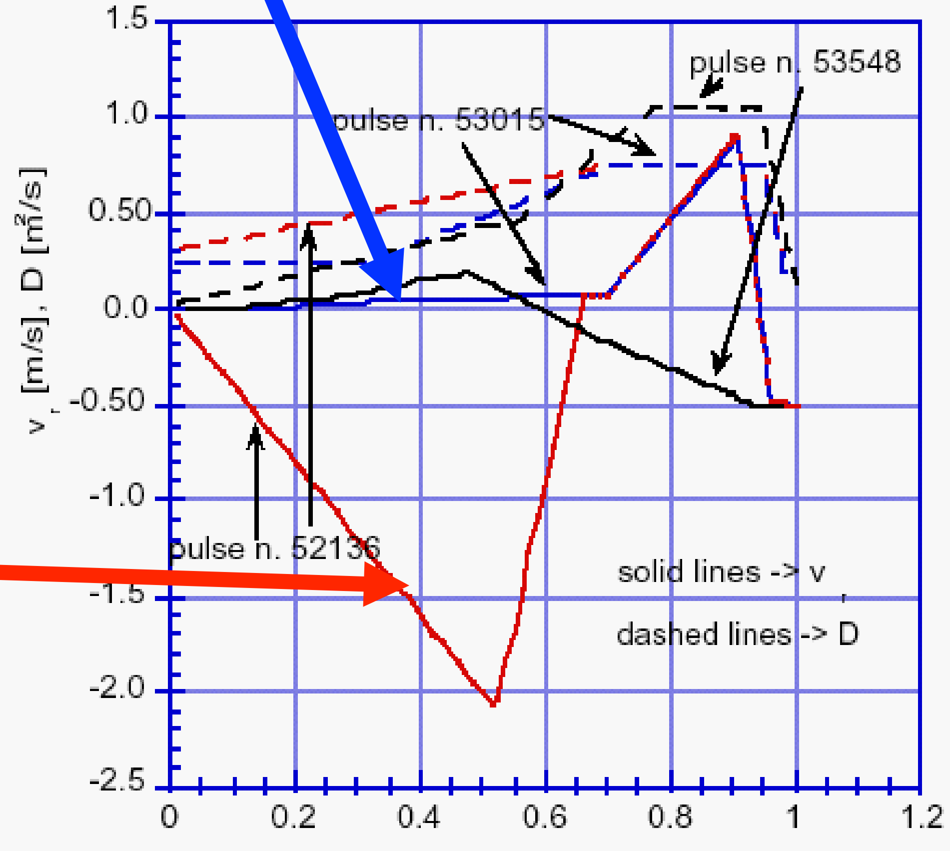
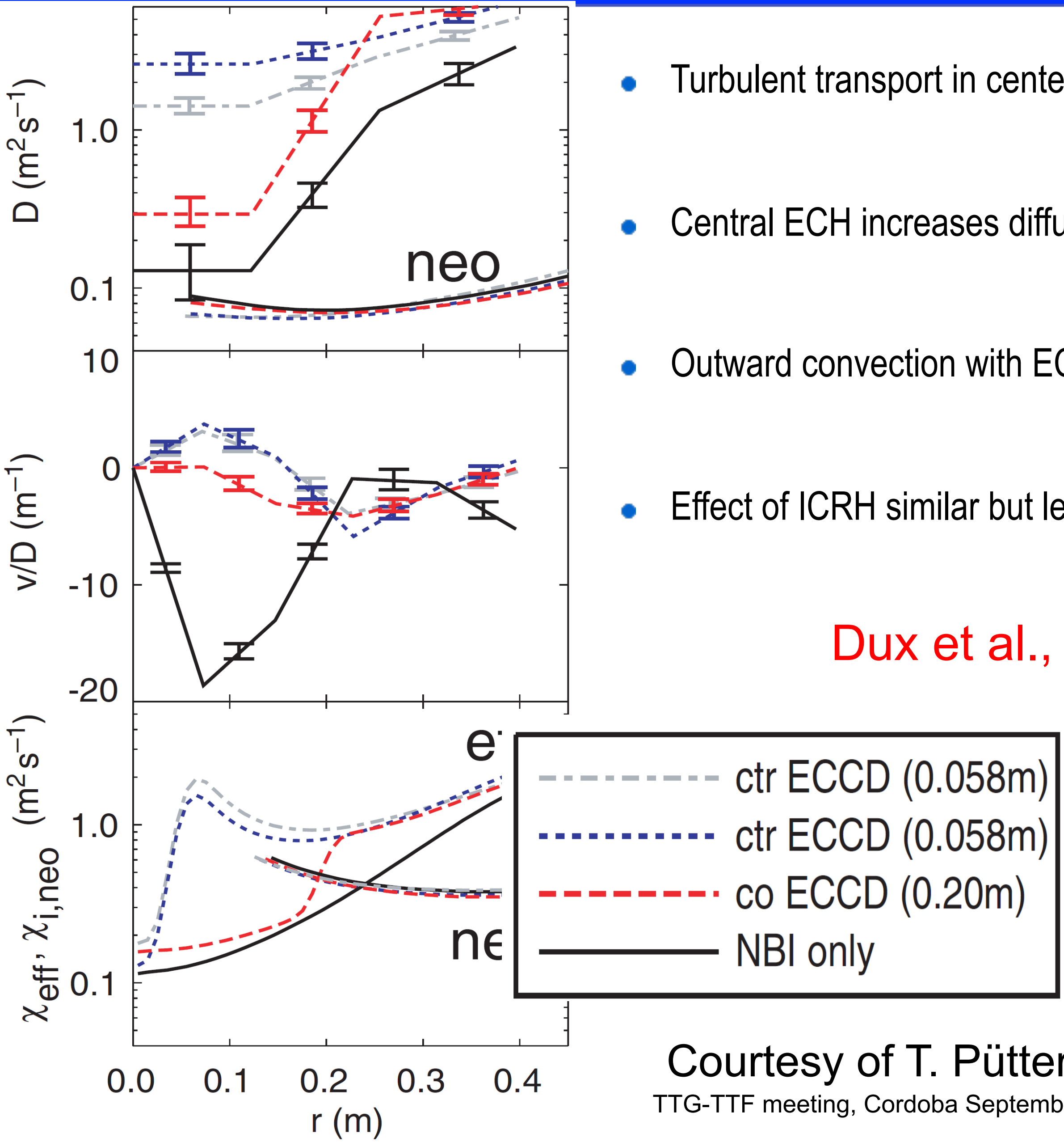


Fig.3

M.E. Puiatti et al .Plas. Phys.Contr. Fus. 44(2002)1863

Impurity pump out in AUG

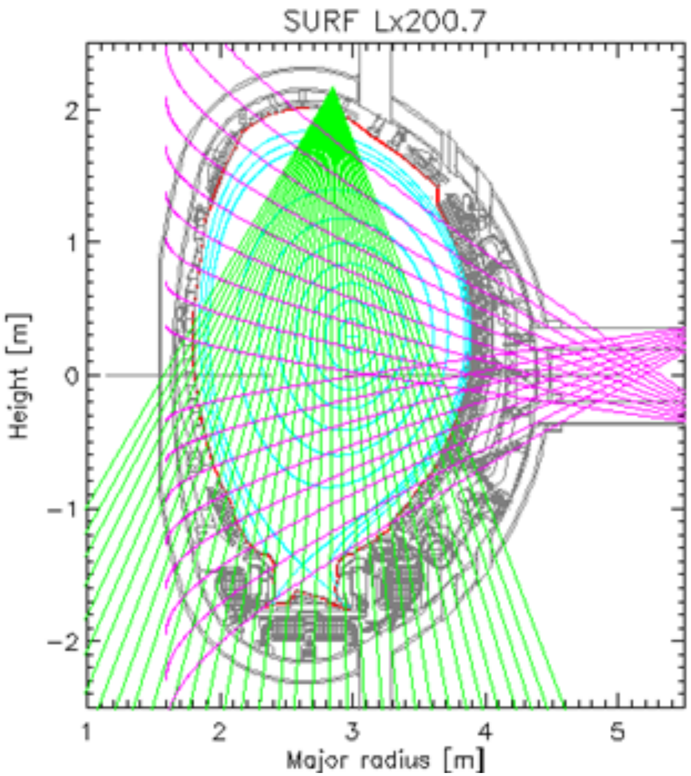


- Turbulent transport in center small, dependent on heating
- Central ECH increases diffusion and reduces inward pinch
- Outward convection with ECH real?
- Effect of ICRH similar but less pronounced

Dux et al., PPCF 45, 2003

Courtesy of T. Pütterich @ EFPW 2009, Hungary

JET SXR L-O-S geomketry



Soft-X rays: a vertical camera with 34 l-o-s (250μ filter)

and

a horizontal camera with 17 channels (350μ filter).